ESA–MOST Dragon Cooperation

2019 DRAGON 4 SYMPOSIUM

24–28 June 2019 | Ljubljana, Slovenia

中国科技部-欧洲空间局“龙计划”合作

2019 年“龙计划”四期学术研讨会

2019 年6月 24–28 日 斯洛文尼亚 卢布尔雅那

3D Tomographic SAR Imaging: a status report

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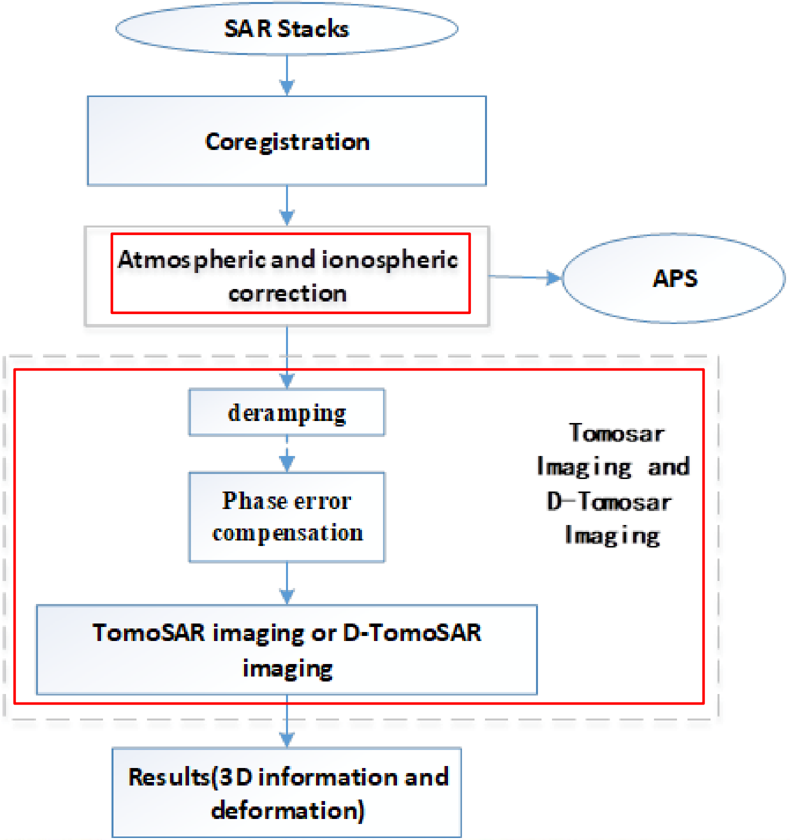
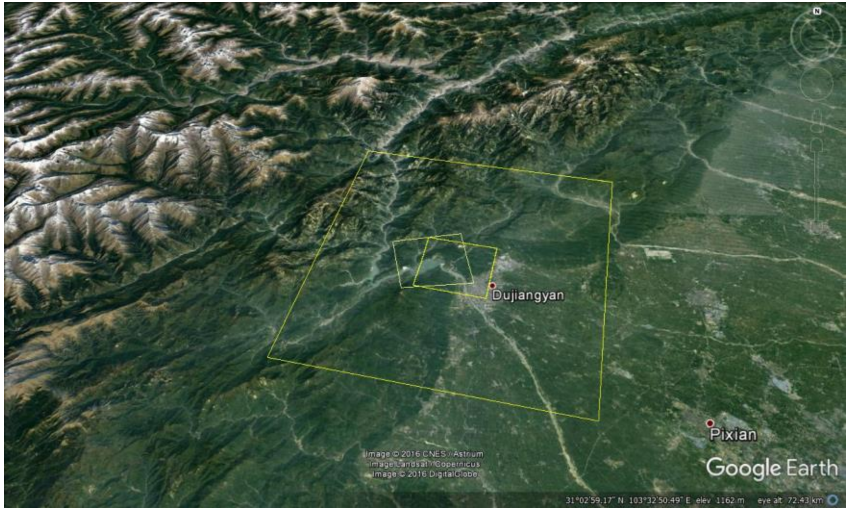
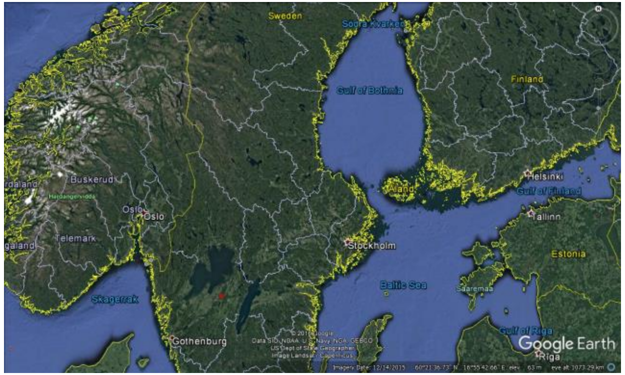
3D&4D TomoSAR workflow



Test sites

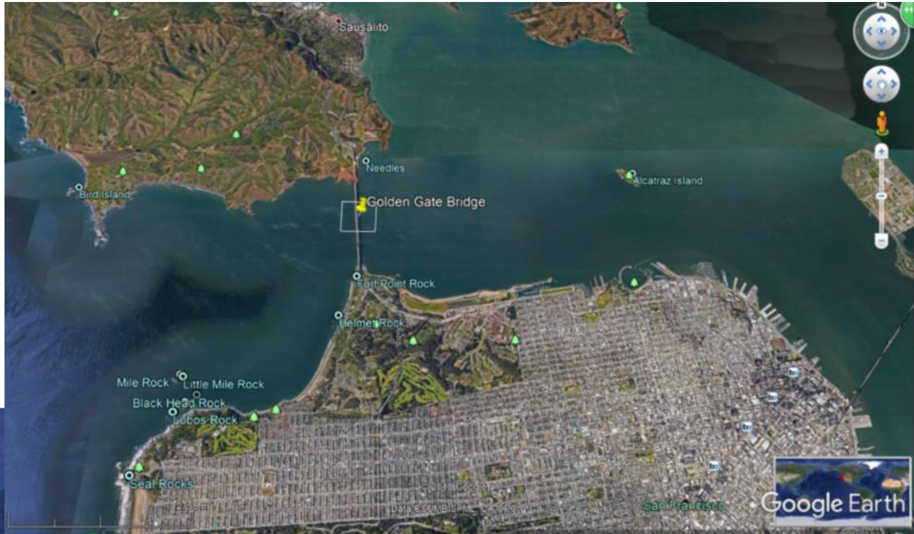


Dujiangyan dam sichuan (cosomo X band 1m) in China

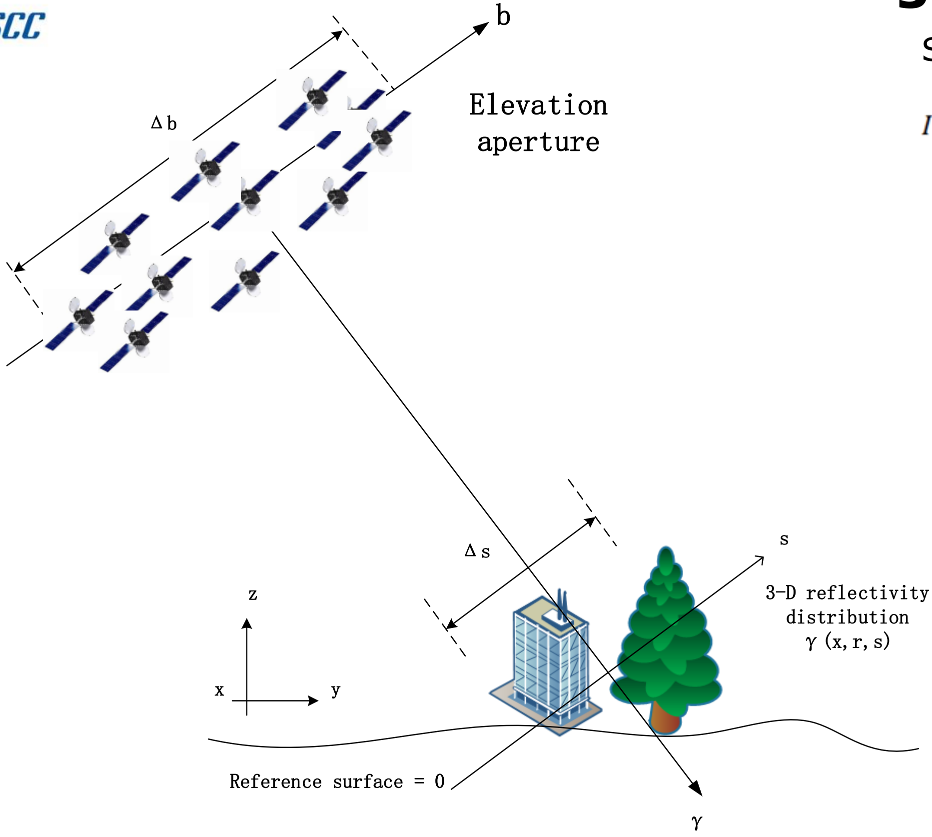


BioSAR 2008 (L band) in Sweden

Alos (L band) Test over San Francisco



3D&4D TomoSAR algorithm



SAR data:

$$I(r,x) = \int_C A(x,y,z) \cdot e^{-j\frac{4\pi}{\lambda}R(x,y,z)} dxdydz$$

$C = resolution\ cell$

mathematical derivation to:

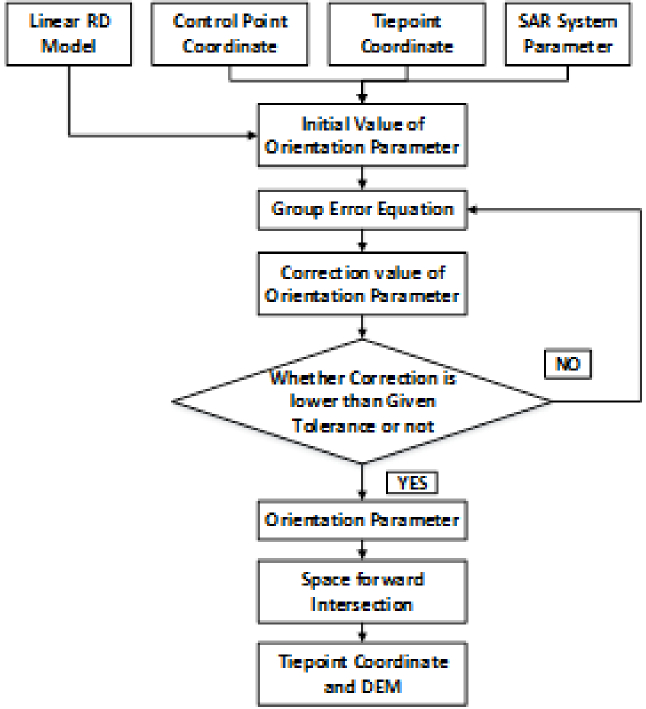
$$y_n = \int_{-p}^{p} \gamma(p) exp[-j\varphi_n(p)]dp,$$

$$P = [s, v]$$

$$\varphi_n(s,v) = [\Delta r_n(s) + v t_n],$$

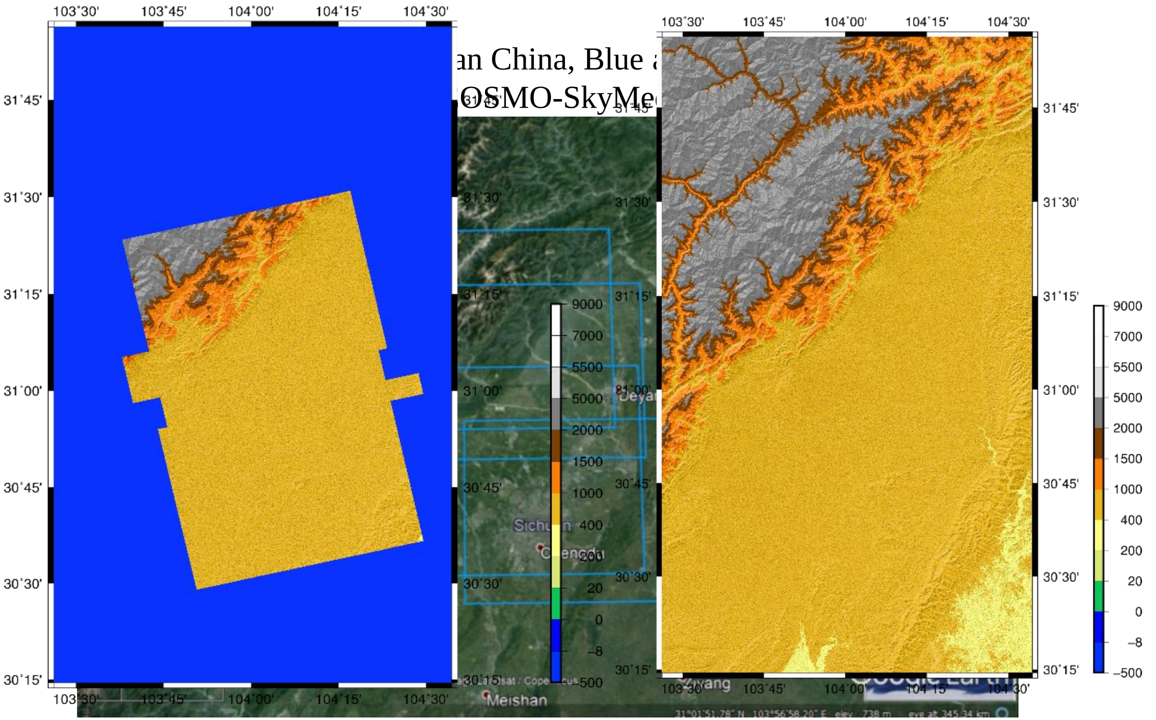
$P = [s, v]$ (s is Elevation, v is Velocity) is what we need to calculate in our Inversion algorithm

DEM generation by radargrammetry



Radargrammetry workflow

Mean difference: 0.03 m, standard deviation: 7.4 m

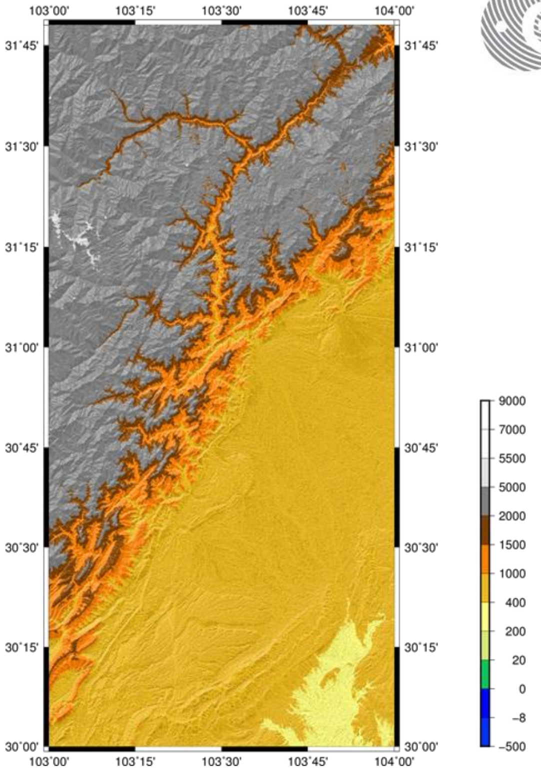


L band Radargrammetry DEM (30 m) with via Bundle Adjustment (BA)

SRTM 1 arc data

Co-registration

All co-registered with subpixel accuracy to the reference master SAR image via DEM(TDX-DEM 12m and SRTM DEM and DEM from INSAR & Radargrammetry) as control points; Simulation amplitude SAR image based on master image orbit information and DEM in radar coordinate system, then matching the master image, all other slave images with simulated SAR image. In this way, all SAR images is co registered based on DEM.

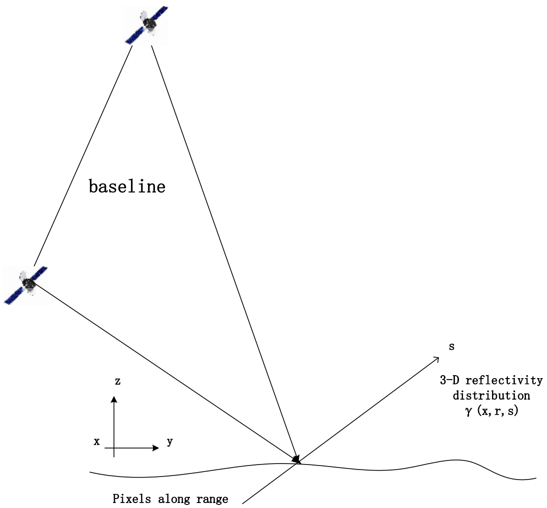


TanDEM-X 12m DEM data after hole replacement, Noise Removal and Smooth filtering

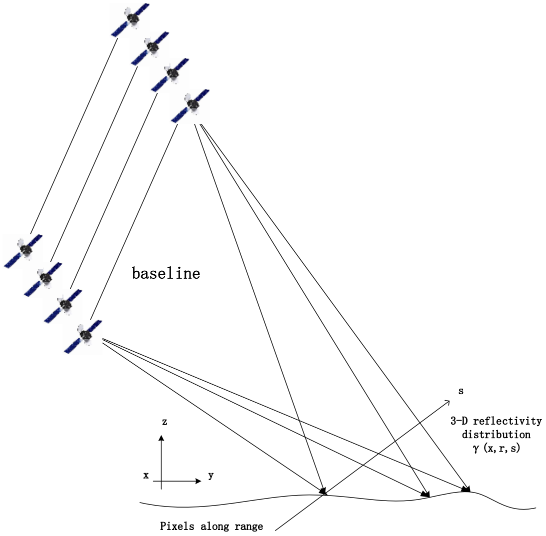
Orbit algorithm-baseline estimation

Studied and developed Orbit algorithm to get baseline:

pixel by pixel baseline Orbit algorithm based on precise time after co-registration with orbit information.



Single baseline



Pixel by pixel baseline

Deramping

$Q(n)$ is SLC data

$$g(n) = exp\left(j\frac{4\pi f_0}{c}R_n(0)\right)\cdot Q(n)$$

$$\exp\left[-j\frac{4\pi}{\lambda}r\right]g_n$$

$$=\int_{-s_{\max}}^{s_{\max}}\exp\left[-j\frac{4\pi}{\lambda}r\right]y(s)\exp\{j2\pi\xi_n s\}ds$$

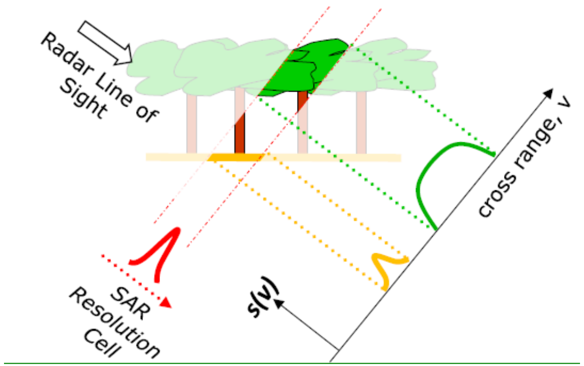
$$p(\xi_n)=\int_{-s_{\max}}^{s_{\max}}\gamma'(s)\exp(j2\pi\xi_n s)ds$$

$$p(\xi_n)=\exp(j\cdot\phi_n)\cdot h_n$$

$$\varphi_n=-\frac{4\pi}{\lambda}[r-r_n(0)]$$

- Deramping compensation via external DEM

Starting from the orbit state vectors and with respect to a reference DEM instead of compensating for the slant range from the radar antenna phase centre to the phase centre of the image pixel, as atmosphere influence



Atmosphere correction

1) Spectrometers:

- MERIS (Envisat)
- MODIS (AQUA and TERRA)

2) Weather model :

- ERA-I (ECWF)
- MERRA
- MERRA2
- WRF

4) Phase-based :

- Uniform correction and Non-uniform correction

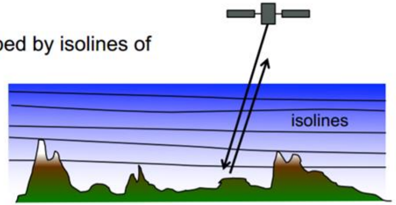
5) GACOS (GPS + DEM + ECWF high resolution)

6) GPS

7) PS method

The **troposphere** is mainly described by isolines of

- Temperature (*T*)
- Pressure (*P*)
- Water vapor (*e*)



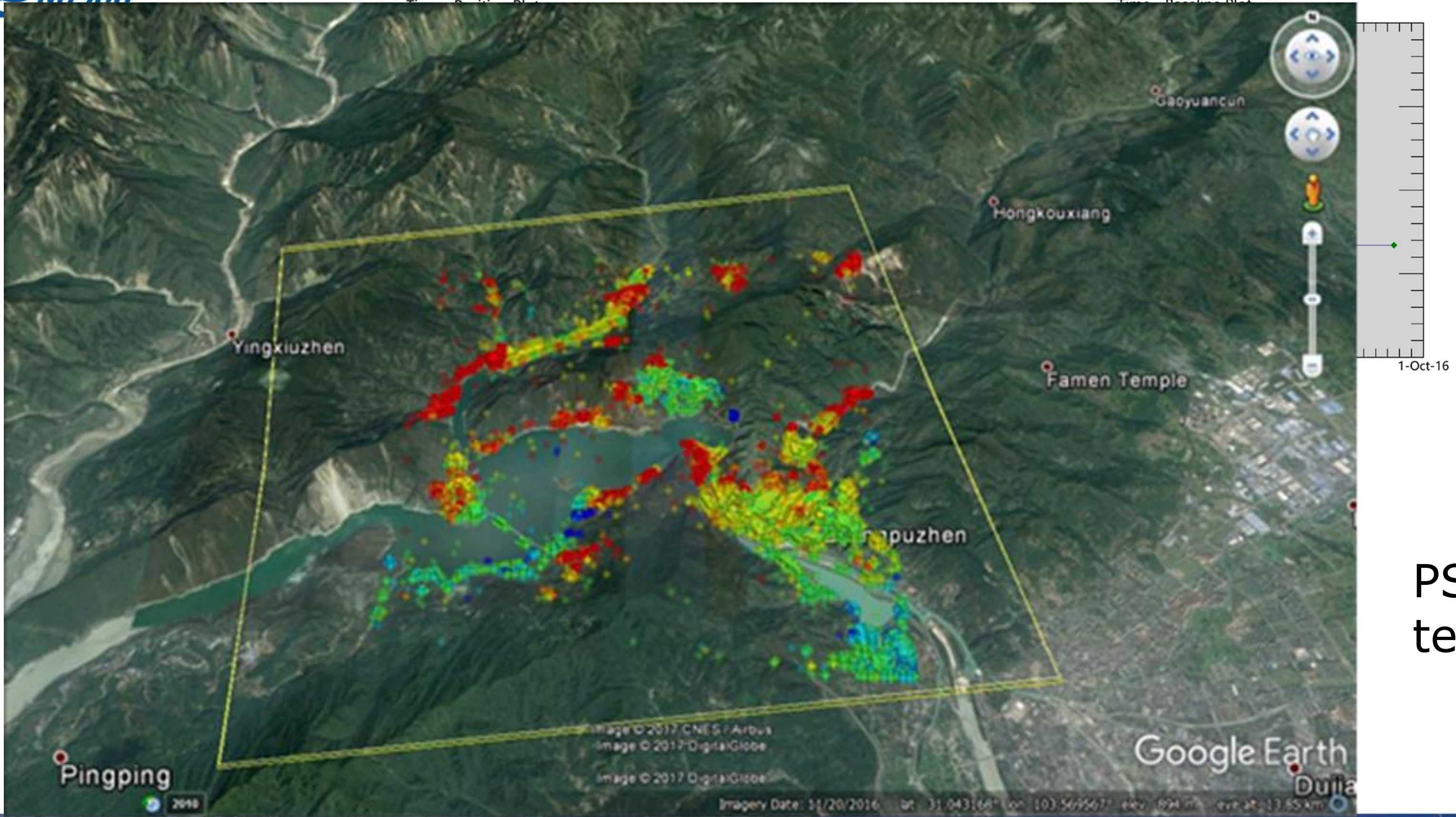
And can be computed by integrating the refractivity *N* with height

$$\phi_{tropo} = \frac{-4\pi}{\lambda} \frac{1}{10^6 \cos\theta} \int_{h=h_1}^{\infty} N dh \qquad N = \left[k_1 \frac{P}{T}\right]_{hydr} + \left[k_2' \frac{e}{T} + k_3 \frac{e}{T^2}\right]_{wet}$$

constants

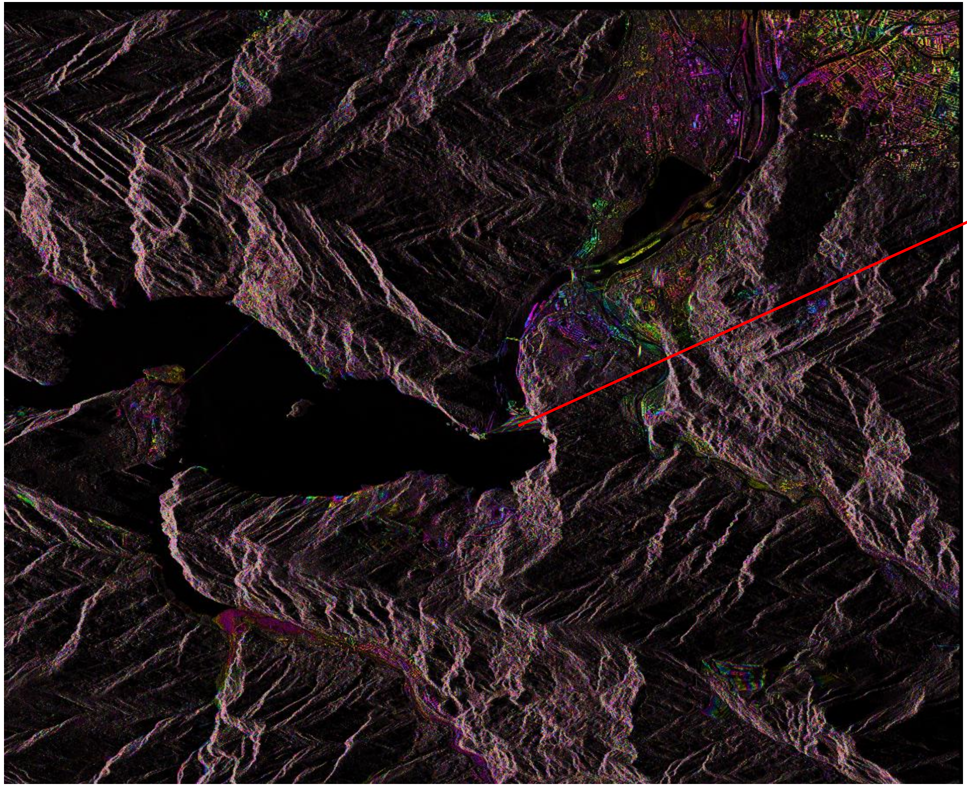
David Bekaert 2016 , Zhenghong Li 2009,2010,2011, Davies et al., 1985 Radio Science; Hanssen, 20051

TomoSAR- PS for atmosphere correction

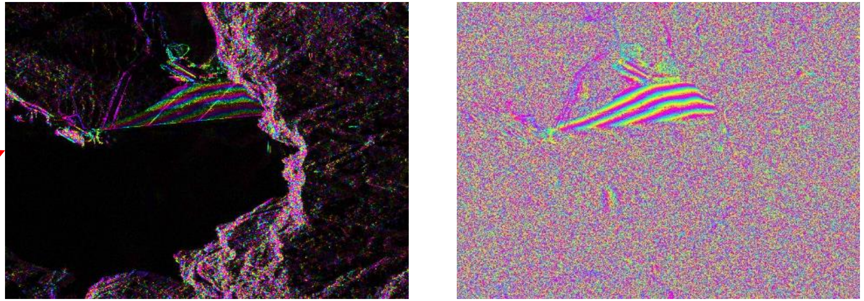


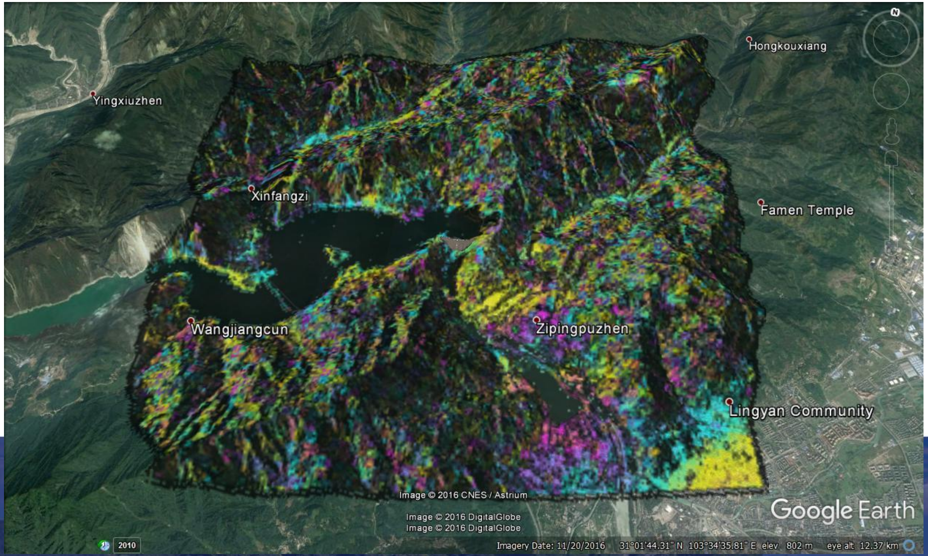
PS points in test area

Interferometry for PS for atmosphere correction



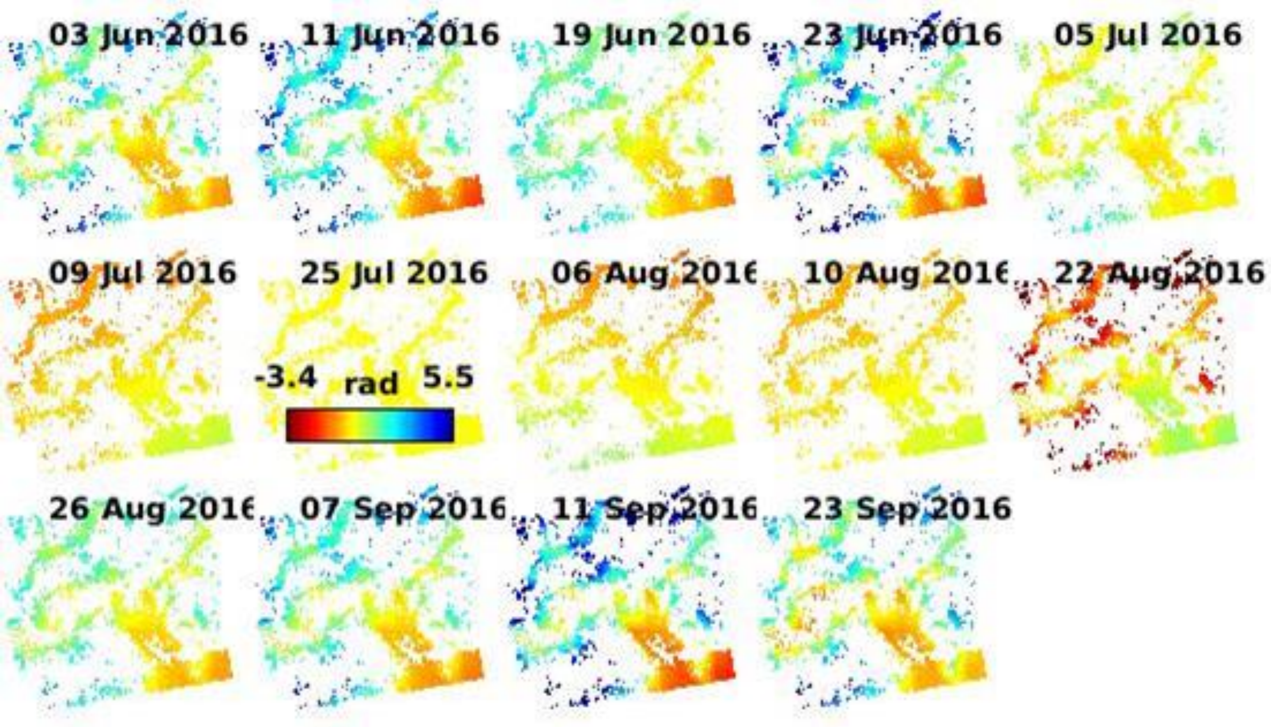
Interferometry results between 20160603 and 20160725





PS- ERA-I model atmosphere total phase

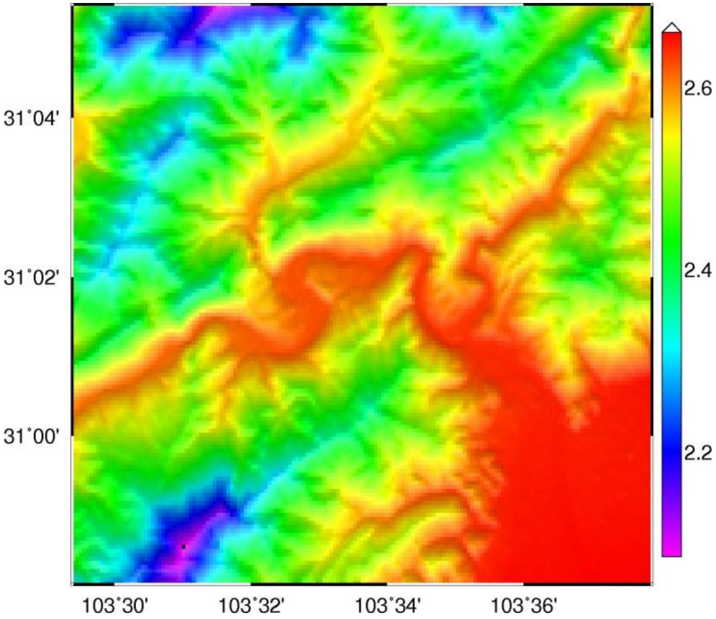
- PS and Tomosar stacks Reference Date[25-JUL-2016]



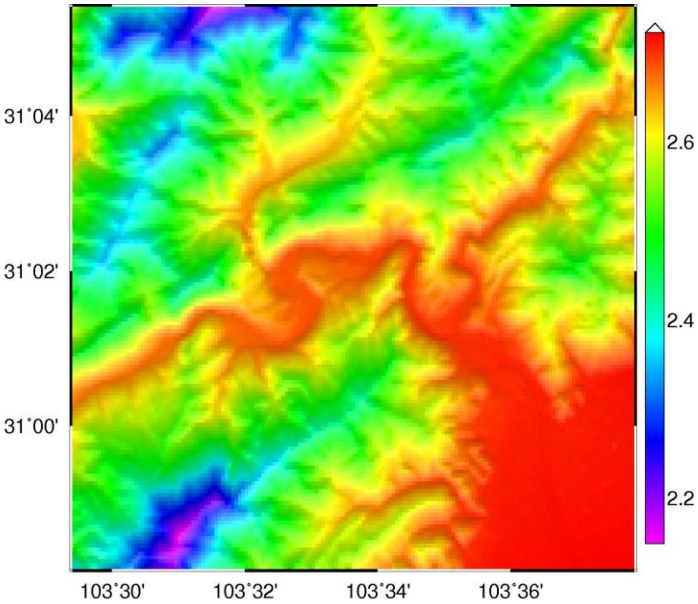
ERA-I model atmosphere total phase (hydrostatic and wet delay) related to the master total phase

GACOS (GPS + DEM + ECWF high resolution) for atmosphere correction

- GACOS ZTD map



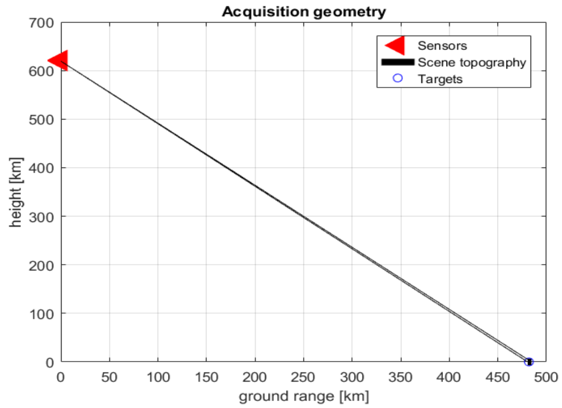
ZTD of 20160603



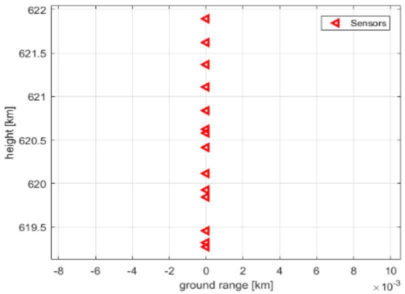
ZTD of 20160725 (master)

Yu, C., N. T. Penna, and Z. Li (2017), Generation of real-time mode high-resolution water vapor fields from GPS observations, Journal of Geophysical Research: Atmospheres, 122, 2008–2025.

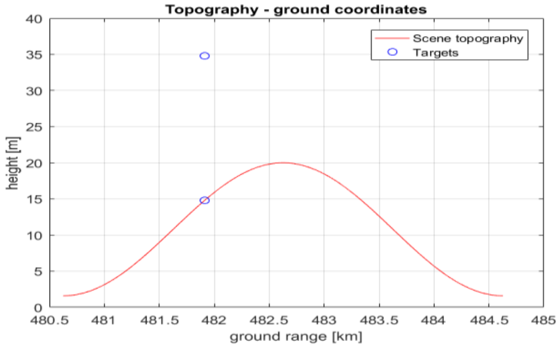
TomoSAR Imaging Spaceborne X-band Simulation and 3D imaging Results



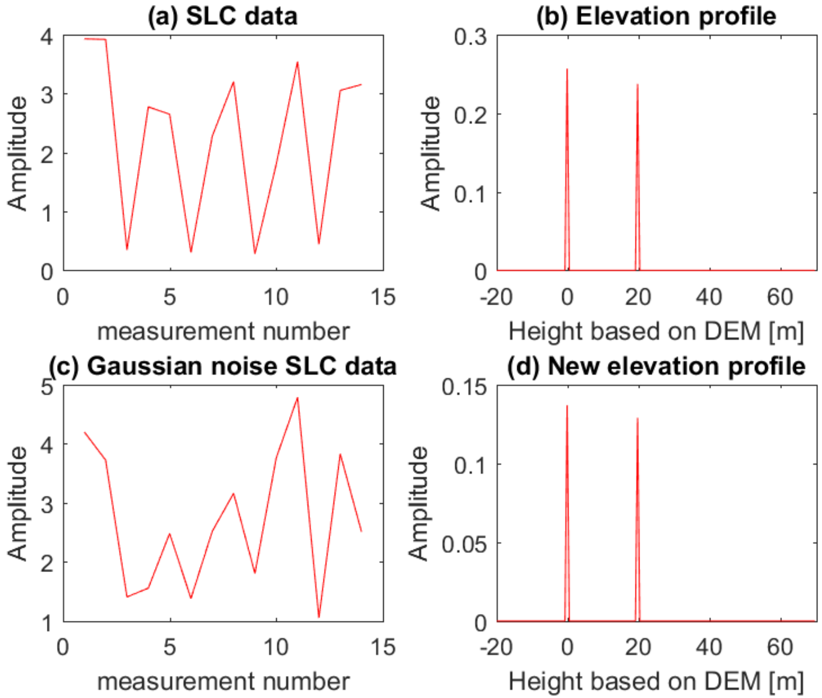
Acquisition geometry of the simulation



The position of the SAR sensors of the 14 measurements. The perpendicular baseline is 50-400m (height ambiguity is 30-240m)



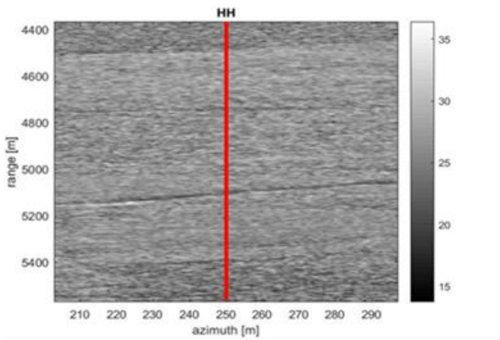
Topography and targets in the ground coordinate system, the simulation targets are at 15 m and 35 m in the vertical direction



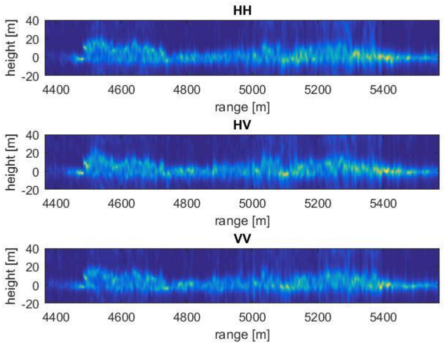
The SAR measure signal, the SAR measure signal adding white Gaussian noise and their CS inversion results

TomoSAR Results in Sweden

a) BioSAR 2008 in Sweden – ESA

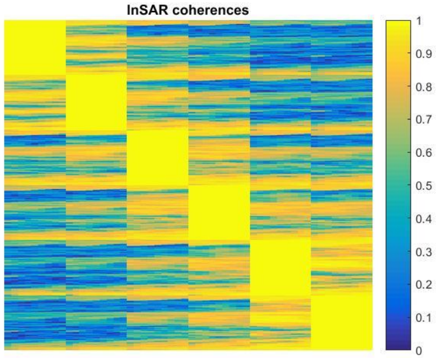


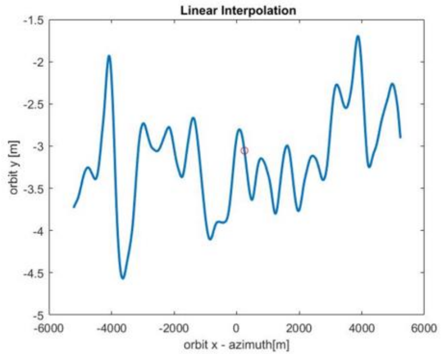
b) SAR imaging in Sweden



c) Tomogram of red line in fig b via FFT

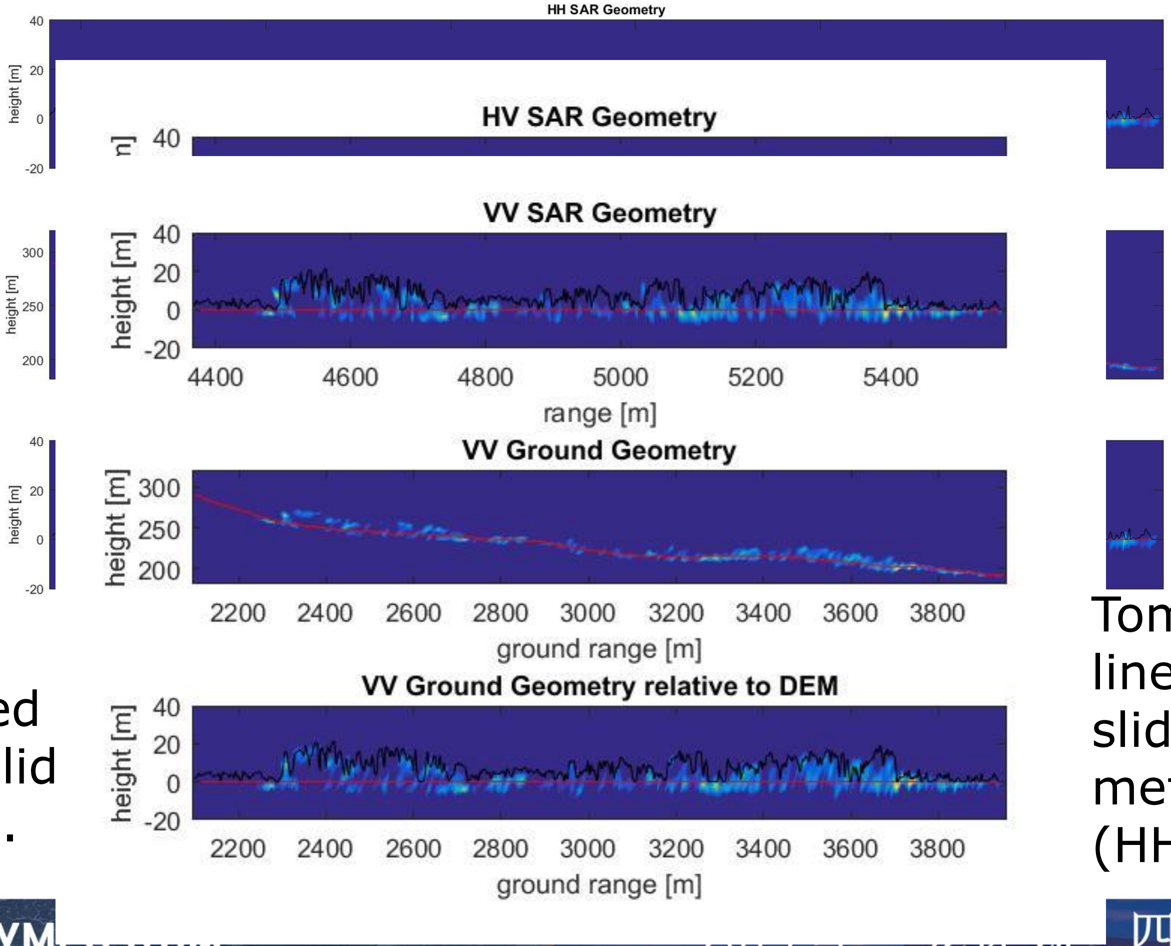
d) Coherence





e) Orbit in x y plane

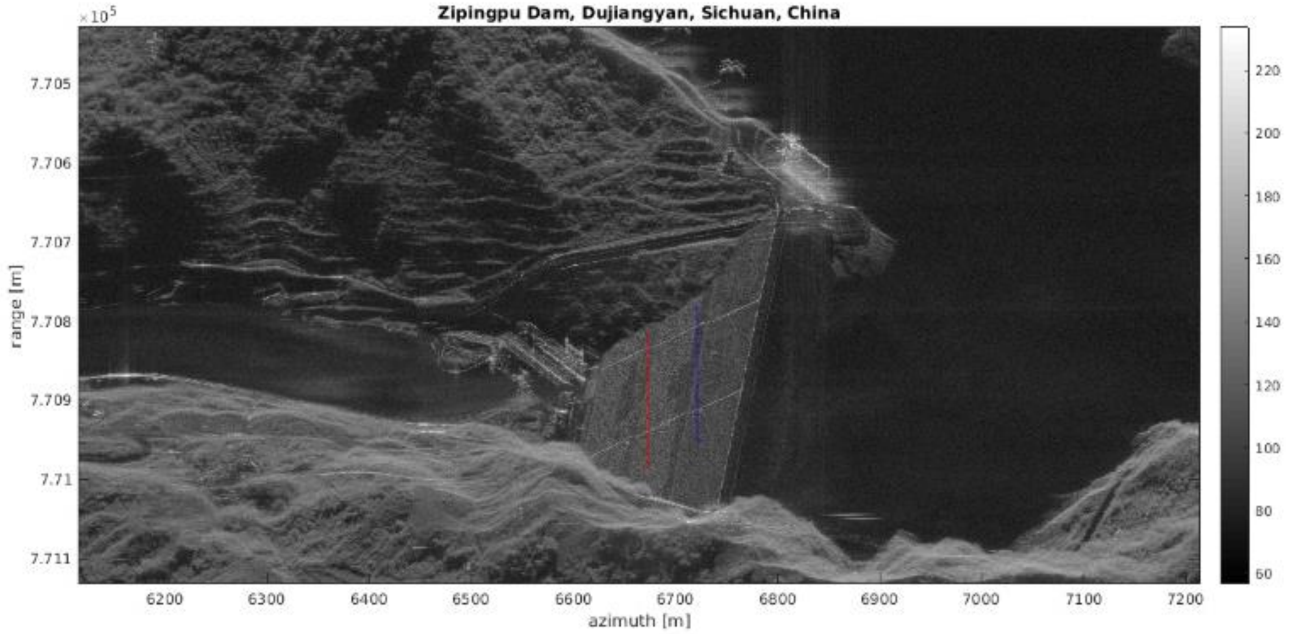
The black line is LIDAR data

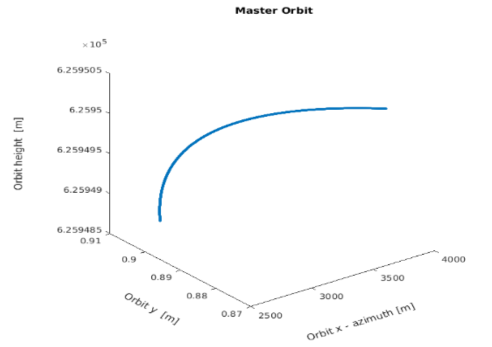


Tomogram of red in fig b in last slid via FFT method.
(HH)

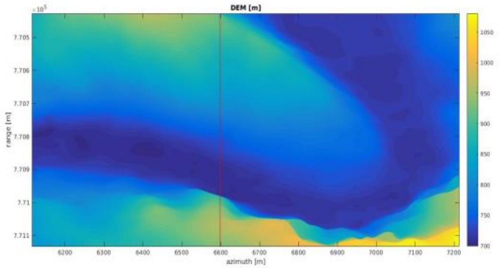
Tomogram of red line in fig b in last slide via Capon method.
(HH ,VV and HV)

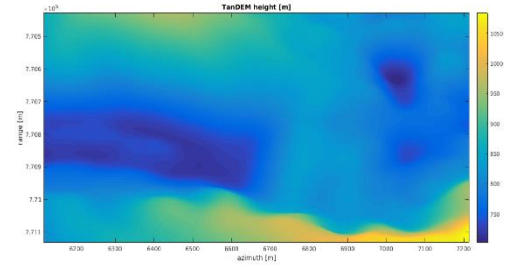
TomoSAR Test in Zipingpu Dam,China





b) Master Orbit(x, y, z)



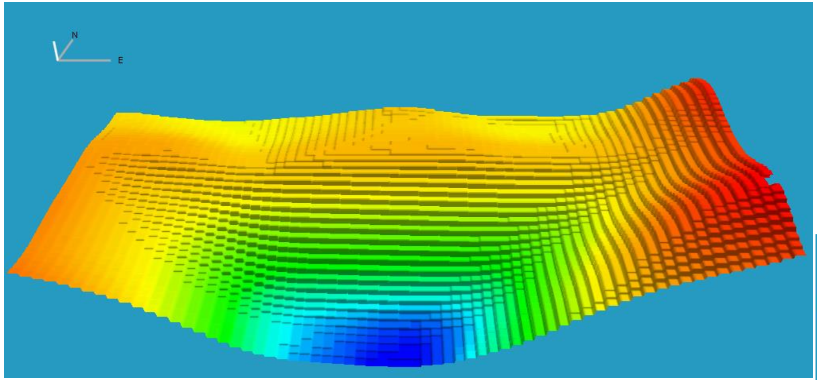


a) SAR imaging stacks mean map

c)SRTM 30m DEM

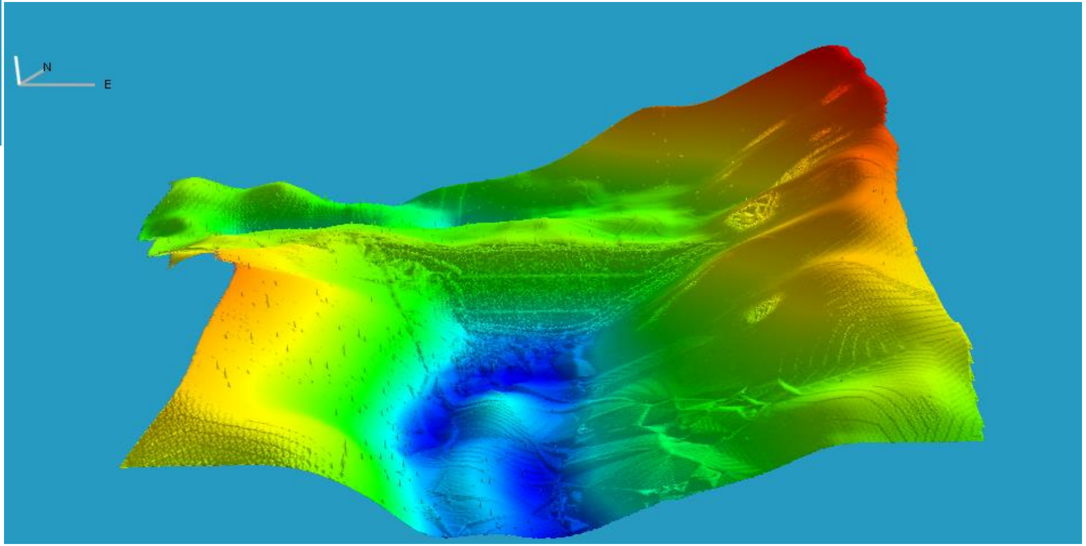
d) TanDEM-X DEM 12m DEM

TomoSAR Height inversion Results via Compressive sensing (CS)

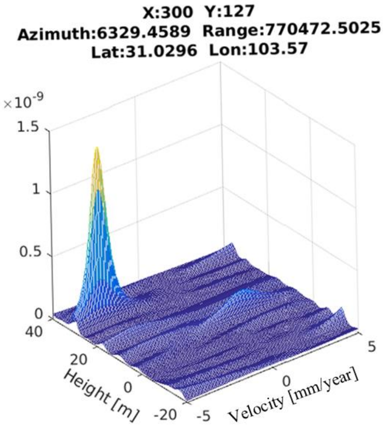


TanDEM-X 12m DEM
(12 m resolution)

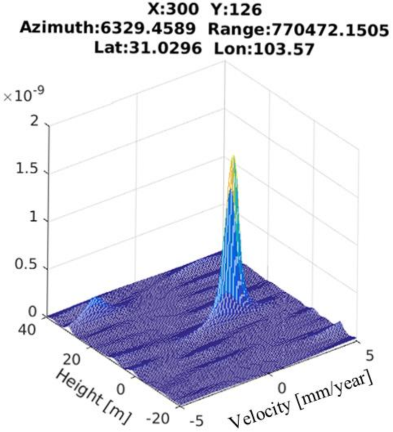
TomoSAR imaging result of COSMO-SkyMed Spotlight data (1 m resolution)



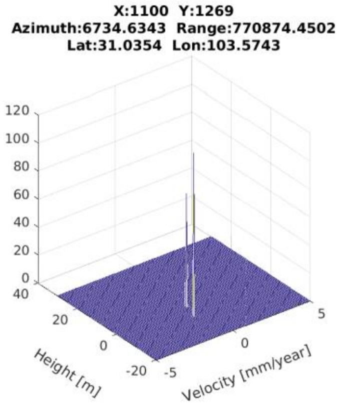
TomoSAR Height and deformation Results via CS

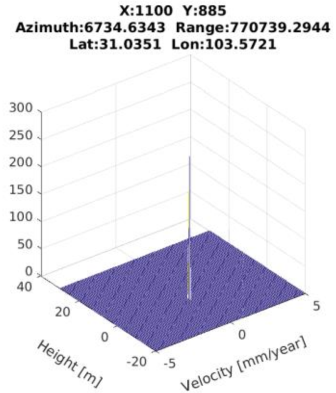


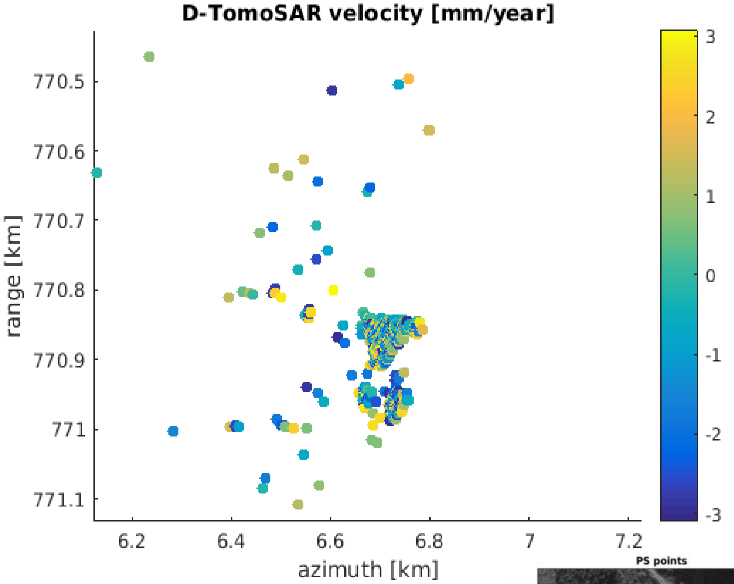
(a)



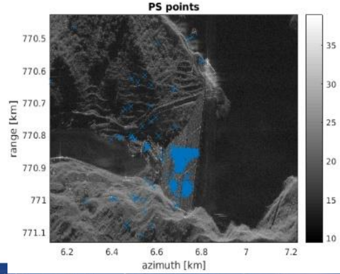
(b)



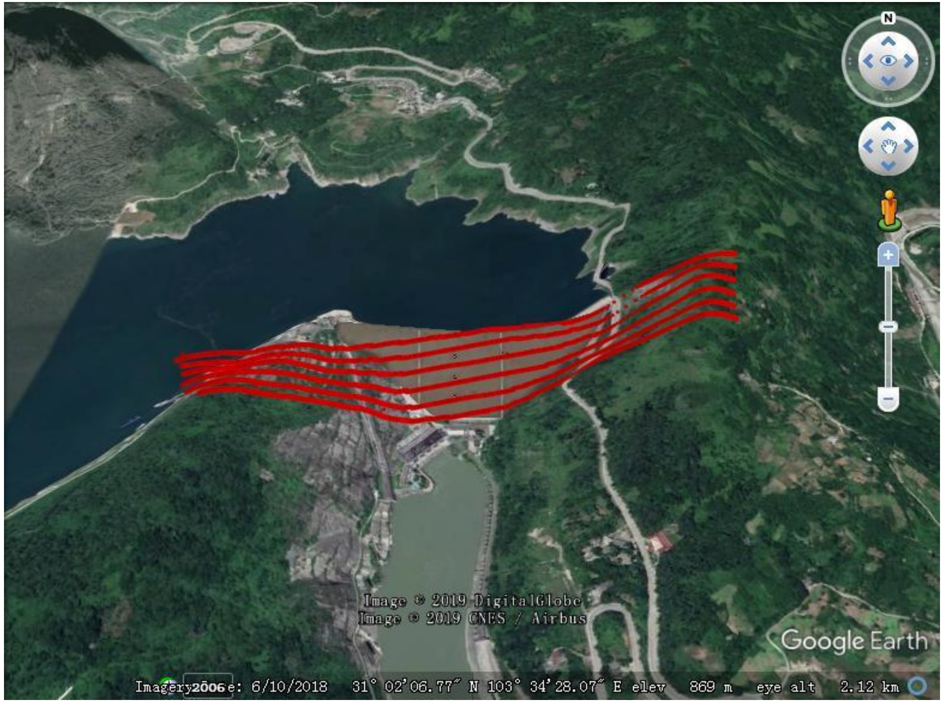




D-TomoSAR velocity at Zipingpu dam



3D display TomoSAR point cloud results at Zipingpu DAM ,China



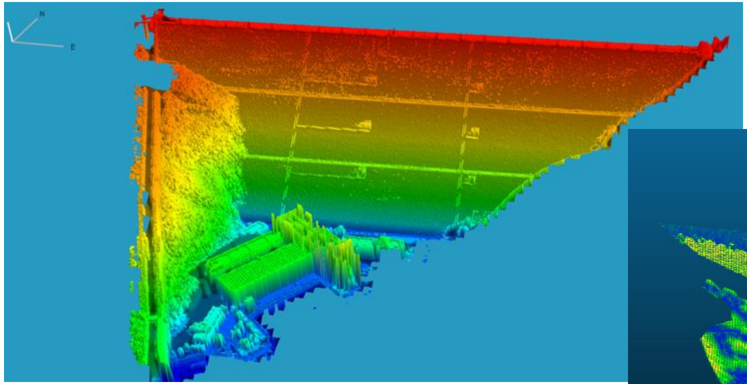
3D display TomoSAR results

Field work for validation at Zipingpu dam

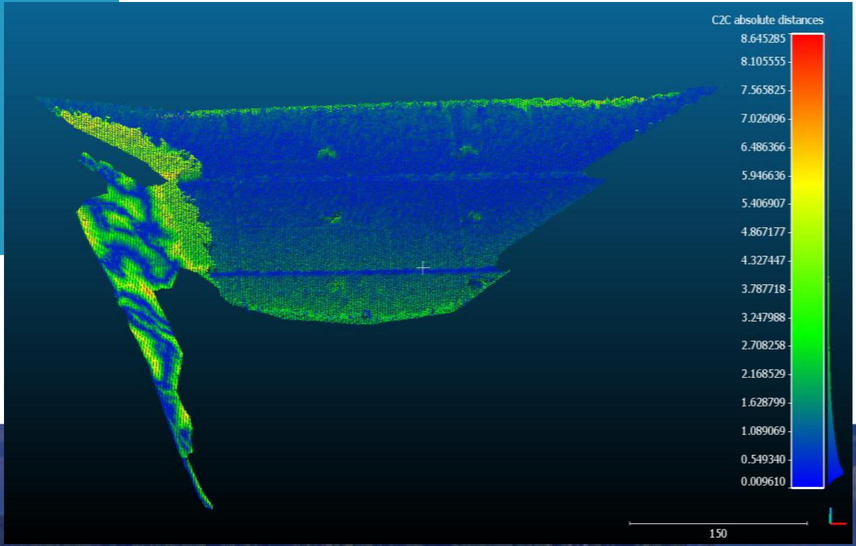
Basic Stats	Area	Min	Max	Mean(m)	Stdev σ(m)
TomoSAR- LIDAR	Dam and mountain trees	0	8.6	0.77	1.88
TomoSAR- LIDAR	Dam	0	5.3	0.18	0.98

Chinese Gao fen Image

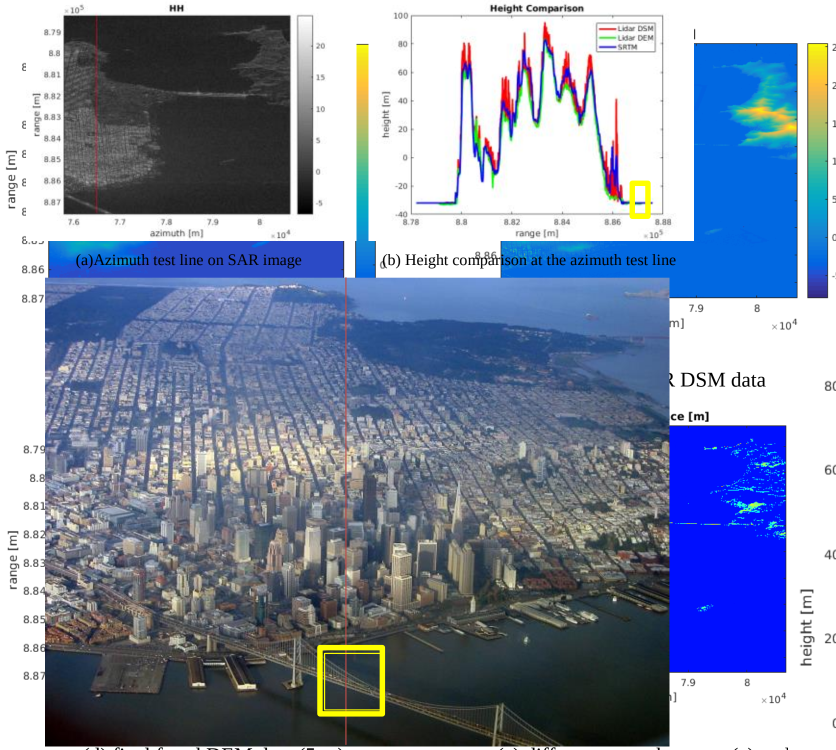
Lidar point cloud of Zipingpu dam



Difference map between X-band TomoSAR imaging result and LIDAR data



TomoSAR Height inversion Results via Compressive sensing (CS) over San Francisco



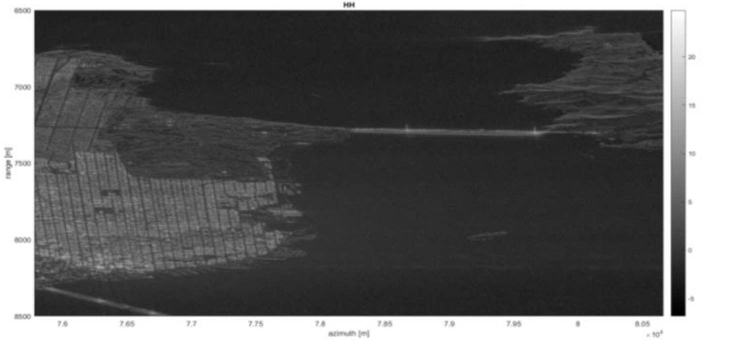
(a)Azimuth test line on SAR image

(b) Height comparison at the azimuth test line

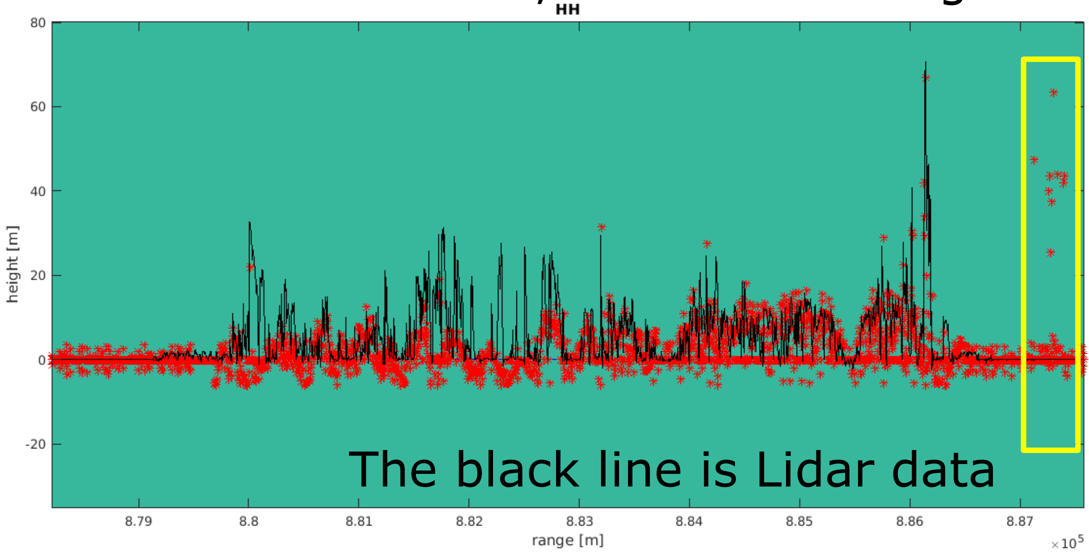
(d) final fused DEM data (5 m)

(e) difference map between (c) and

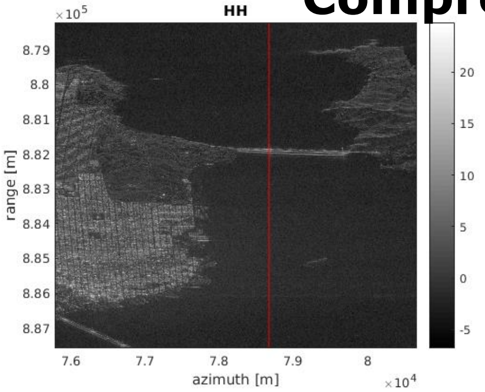
(c) The test line (red) on the image of the building area of San Francisco Bay, USA, Copyright © 2007 FreeLargePhotos.com.



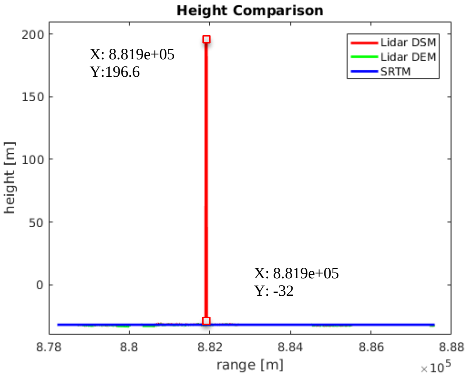
No Lidar data here, but CS can image it



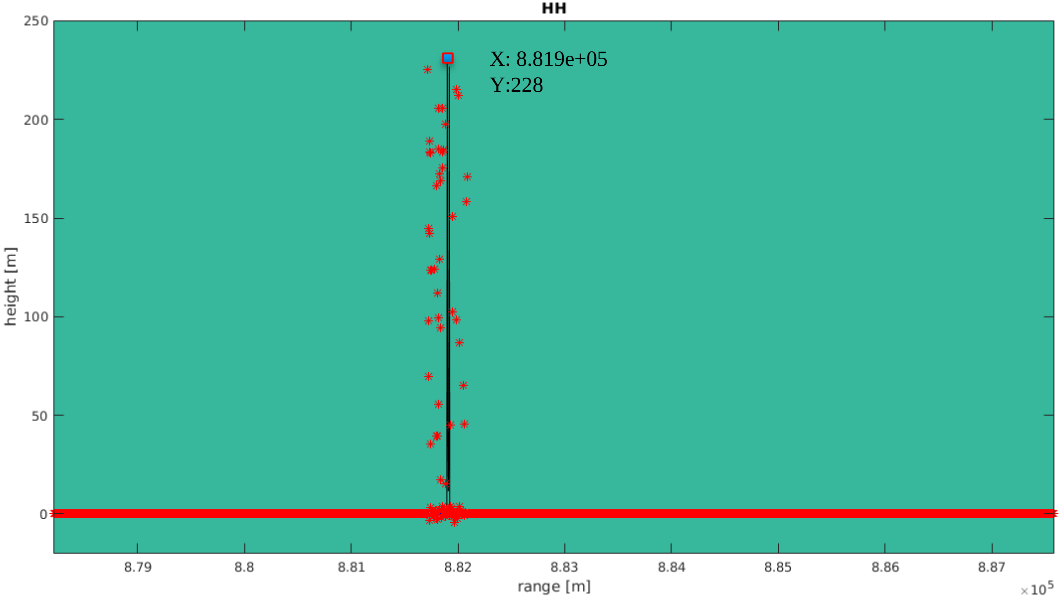
TomoSAR Height inversion Results via Compressive sensing (CS) over San Francisco



(a) Azimuth test line on SAR image



(b) Height comparison at the azimuth test line



Conclusion

- Tomographic data exhibit a more complex dependence of terrain topography than traditional SAR data.
- Lidar forest height is not matched in Sar geometry, while it is well matched in ground geometry relative to DEM.
- Orbital, tropospheric phase distortion and DEM correction are indispensable in 3-D SAR imaging (SAR tomography) and 4-D SAR imaging methods via Compressive sensing.
- The results demonstrate that L band data are fit for the structure reconstruction of forests and manufacture facilities (bridge, building, and so on), but the resolution is not very high. X band has little penetration capability, which cannot be used for forest structure reconstruction. However, it can be used for 3D TomoSAR imaging, the retrieval of the top position of the canopy, the shape of the man-made structure (dam, buildings and manufactured facilities) and the top of the 3D terrain, which is best for high resolution DSM acquisition and target detection.

Acknowledgement

- Many thanks to CSC and UCL MAPS Dean prize through a PhD studentship at UCL-MSSL.
- Many thanks to Space Catapult, Harwell space campus and Terri Freemantle, in particular, for arranging the provision of CORSAIR011 data.
- Many thanks to Prof. jingfa Zhang, Dr. Qisong Jiao and Dr. Hongbo Jiang from Institute of Crustal Dynamics, China Earthquake Administration for 2017 field work and collaborations.
- Many thanks to Prof. Zhenhong Li for his valuable advice and providing GACOS data.
- Many thanks to COMET for organizing INSAR TRAINING WORKSHOP 2017.
- Many thanks to Randolph Kirk (USGS), Elpitha Howington-Kraus (USGS) for DEM code.
- Many thanks to Stefano Tebaldini (Politecnicodi Milano) , Laurent Ferro-Famil (University of Rennes) for data and code and ESA for data and organizing the ESA 4th advanced course on radar polarimetry .

Thank you!